The Quindalup Dunes: the regional system, physical framework and vegetation habitats

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Abstract

The Quindalup Dunes contain a variety of aeolian landforms developed by regional climatic, geomorphic and sedimentologic factors, as well as local coastal/strandline processes, and vegetative and pedogenic processes. Superimposed on these are factors of distance from the strandline (which determines the degree of wind effects), soil salinity, and height above water table (which is related to height above sealevel). These factors and processes have resulted in a range of geomorphic units, habitats and vegetation responses that can be recognized at various scales of reference.

A consistent terminology for geomorphic units and habitats has been developed in order to compare tracts of Quindalup Dunes along the various sectors of the southern west coast of Western Australia. The large to medium scale geomorphic units include parabolic dunes, chaots (chaotic dune terrain), shore-parallel ridges, blowouts, undulating plain and flats. The small scale geomorphic units, that essentially equate with the basic vegetation habitats, are subdivisions of the larger scale geomorphic units; these include various slope units; crests and depressions of the larger scale units.

Each of the five sectors of the south west coast of Western Australia contains distinct associations of geomorphic units and vegetation habitats that reflect a difference in the regional sedimentological and geomorphic setting, as well as gradients in climate and other edaphic factors. Changes in dominant habitat types from sector to sector, together with the climatic gradient, favour smaller scale heterogeneous distribution in the structure and floristics of the vegetation units along the extent of the Quindalup Dunes. Our analysis of the distribution of reserves for flora and fauna within the Quindalup Dunes indicates that the regional variety of landforms and vegetation habitats is not adequately represented. In particular, there is no reservation of Quindalup landforms and habitats representative of Geographe Bay, the barrier dunes of Leschenault-Preston Sector, and the cuspate beachridge plain exemplified by Point Becher.

Introduction

The Holocene coastal dune zone of the Swan Coastal Plain is generally a relatively narrow assemblage of landforms formally termed the Quindalup Dunes (McArthur & Bettenay 1960). The zone extends from Dunsborough in the south to Dongara in the north along the south west coast of Western Australia. Within this zone various authors have described and mapped vegetation, or landforms related to vegetation.

Smith (1973) provided a guide to the flora of the coastal habitats and subdivided the flora of dunes into 4 types: foredune vegetation; mobile dune vegetation; stabilized dune vegetation; and tall closed dune scrub. Smith (1985) later subdivided the dune vegetation into 3 types, apparently excising the tall closed dune scrub from the classification. A number of later authors, particularly in unpublished government reports, adopted the subdivision of Smith (1973) as the basic vegetation units of the Quindalup Dunes. Speck (1952) and Seddon (1972), on the other hand, provided maps of the dune zone, generally treating the vegetation complexes within the Quindalup Dunes as a single unit. Heddle (1979), Heddle et al (1980) and Beard (1976, 1981) similarly mapped the flora of the zone, treating the unit essentially as a homogeneous system although recognizing at least 2 alliances, namely a strand and foredune alliance, and a mobile and stable dune alliance.

McArthur & Bartle (1980a,b) described various stages of Quindalup dune landform evolution (Q1, Q2, Q3 and Q4) and its stabilization by vegetation, and related vegetation assemblages to these landforms. More recently Cresswell & Bridgewater (1985), utilizing a floristic and landform/soil approach, incorporated the Quindalup Dune System into their overall treatment of vegetation of the Swan Coastal Plain. They subdivided the Quindalup Dune vegetation into eight units, which were then related to geomorphic location.

However, the Quindalup Dunes present a much more variable system of habitats than perhaps has been appreciated. The variability in habitat is due to: processes and stages of landform development as determined by regional factors; processes and stages of landform development as determined by local geomorphic history; relative position of landform units with respect to the strandline; relative relief of the various small scale landform units with respect to water table; degree of development of soils and calcrete; and soilwater salinity.

These interacting factors have developed a wide range of small scale geomorphic units each with its own distinct relief, slope, soil cover, and location relative to sea effects. Because geomorphic processes, and the resultant geomorphic units (variable in time, space, intensity of development, and scale), are the fundamental determinants of habitats, a geomorphic approach should provide a useful framework for vegetation studies. The approach adopted here is to describe the geomorphic units and habitats at various scales of reference in the Quindalup Dunes, and to relate them to coastal and aeolian processes and vegetation. This is a direct application of the coastal sector analysis of Searle & Semeniuk (1985) and landform analysis to vegetation investigations. There is a recurring suite of geomorphic units peculiar to each of the 5 coastal sectors of Searle & Semeniuk (1985) and thus the sector approach provides a framework to identifying and understanding the differences within the Quindalup Dunes along their extent. The approach is useful for analysing the Quindalup Dune vegetation regionally and, in combination with the subcontinental gradient of climate and variability in species pool, helps to explain the complicated pattern of habitats and vegetation assemblage within the Quindalup Dune System. Such information is important for studies in conservation, coastal management or assessment of regional significance of vegetation and landforms within a given sector of the Quindalup Dunes.

This paper reports on the first stage of investigations of the vegetation of the Quindalup Dunes. The objectives of the paper are to describe the regional setting, regional variety and the local variability of the physical features of the Quindalup Dunes throughout their full extent along the Swan Coastal Plain so that the physio-chemical framework, geomorphic units and habitats can be identified. As such this paper provides information on geomorphology and vegetation habitats of the Quindalup Dunes to a level not previously reported and provides the basis for more detailed studies of the habitats and vegetation of the Quindalup Dunes in the future.

Methods

The results of this paper are based on intensive fieldwork, reconnaissance field surveys, aerial photograph studies, low altitude aerial surveys and literature review. Fieldwork involved study of geomorphology, stratigraphy, soils and vegetation by surface mapping, coring/trenching and sample collection. The maps produced in this paper are the result of field work supplemented by ground truthing. Aerial photographs and ground surveys were also used to identify the range of geomorphic units in the region. Sites of intensive fieldwork include (Fig. 1): Geographe Bay area, Leschenault Peninsula-Myalup area, Yalgorup National Park-Mandurah area, Pt Becher-Rockingham Plain area, Trigg Island-Whitfords-Two Rocks area, and areas around Lancelin, Cervantes, Jurien Bay, Green Head-Leeman, and Dongara. Intensive fieldwork was supplemented by reconnaissance surveys and low altitude aerial surveys over the remainder of the southwest coast between Geographe Bay and Dongara. Examination of aerial photographs, utilizing black/white and colour photographs, was also undertaken.

The approach of Semeniuk (1986) was used in mapping and naming of geomorphic/habitat units. This method involves identifying units observable and mappable at a given scale of reference. The scales of reference, slightly modified after Semeniuk (1986), are: **regional scale** (100km x 100km frame of reference); **large scale**(10km x 10km frame of reference); **medium scale**(1km x 1km frame of reference); and **small scale** (100m x 100m frame of reference). The same geomorphic unit may be observable at several scales of reference. For example, parabolic dunes may be mappable at regional and large scales. At medium scale, different types of parabolic dunes such as fretted or attenuated, may be identifiable. At small scale only geomorphic sub-units of the parabolic dune may be mappable, such as the crest or bowl.

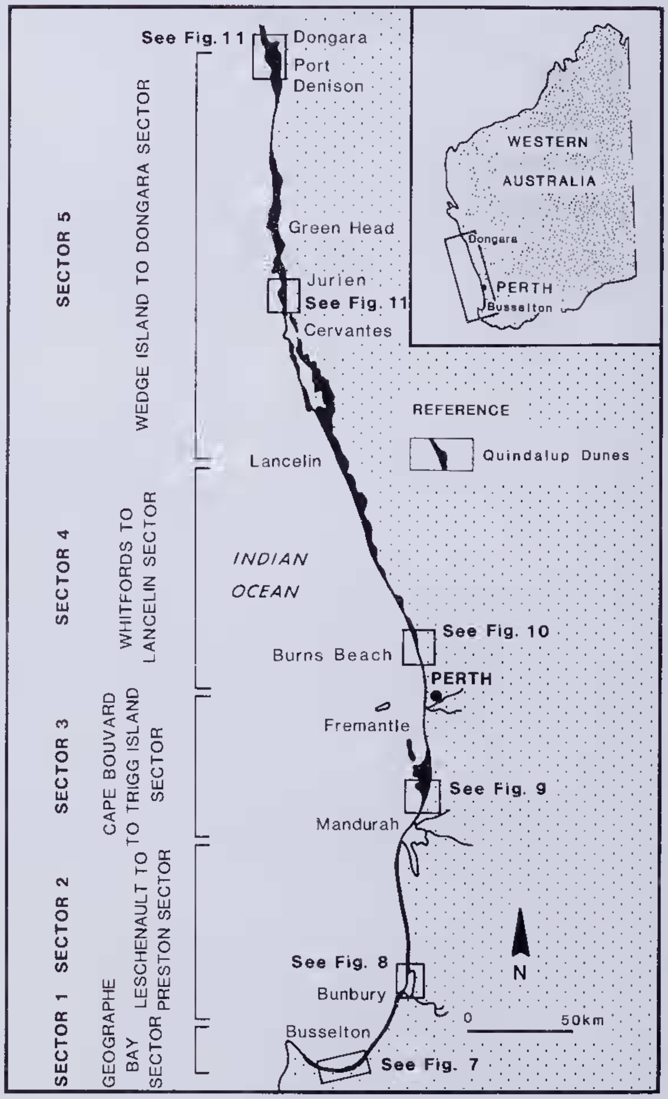


Figure 1 Distribution of Quindalup Dunes and location of study sites in Southwestern Australia.

The stratigraphy of the Quindalup Dune terrain was determined by drilling, trenching and augering, and from information in the literature (Searle 1978, Semeniuk 1983, Woods 1983, Searle & Semeniuk 1985, Semeniuk & Searle 1985a,b 1986). Soil profiles were documented in numerous locations in each of the study sites. The soils were described in terms of humus content, structure, fabric, texture and composition. Soil samples for analyses of salt content were collected along 2-4 transects for each sector. Samples were collected in summer from the shore to the hinterland in transects parallel to the dominant summer wind direction. Sample sites were generally spaced 100m apart for distances 0.5-2.0km along a transect. At each sample site 5 replicate surface soils were collected. In the laboratory soils were dispersed in an aliquot of distilled water to leach out soluble salts and the salinity of the resultant solution was determined by conductivity meter. The salinity results were then converted to mg salt/cm^3 of soil. The organic and humus content of soil was determined by heating soils to >450°C to expel carbon as CO_2.

Regional setting

Geomorphology

The Quindalup Dune System extends along the modern shoreline of the Swan Coastal Plain, spanning a distance from Geographe Bay in the south to Dongara in the north (Gentilli & Fairbridge 1951). It varies from a narrow unit to a locally extensive system up to 10km wide. Topographically the system varies from a low-relief, subdued coastal plain 3-5m above MSL, to steep aeolian highlands with a relative relief of c 30 m. The Quindalup system generally adjoins the older Spearwood Dune system (to landward) but in many locations the Quindalup Dunes are encroaching over the Spearwood Dune terrain.

Climate

The coastal dune belt of the Swan Coastal Plain spans a climate gradient from humid in the south at Geographe Bay to semi-arid at Dongara (Gentilli 1972). Such wide climate variation should influence coastal processes and hence the development of different habitats, dynamics of habitats, availability of water, and consequently the resultant vegetation. The climatic parameters considered most important to development of habitats and to maintenance of vegetation are wind, rainfall, evaporation and temperature. These factors interact to develop a variability in habitat and plant response both regionally and locally. For instance, onshore wind gradually changes in intensity and direction from Geographe Bay to Dongara (Searle & Semeniuk 1985). As a result, blowouts and parabolic dunes increase in number, and the parabolic dunes extend further inland and become more northerly aligned from south to north along the coast. Rainfall, evaporation and temperature also are critical to dune development and vegetation response, and again from south to north there is an increase in aridity reflected by landforms and vegetation. Rainfall, varying from c 500mm/yr in the north to >800mm/yr in the south, determines the amount of moisture available in the vadose zone and the extent to which the groundwater table is salinized. Climate data for selected locations are summarized in Table 1.

Stratigraphy

The sand of the Quindalup Dunes stratigraphically is referred to as Safety Bay Sand. The unit is juxtaposed against the older more landward Spearwood Dune System or Yoongarillup Plain (MacArthur & Bettenay 1960, MacArthur & Bartle 1980a), the underlying materials of which are stratigraphically referred to as Tamala Limestone (Playford *et al* 1976). The Safety Bay Sand also may adjoin and overlie a Holocene seagrass sedimentary unit, the Becher Sand (Semeniuk & Searle 1985b), or an estuarine sedimentary unit, the Leschenault Formation (Semeniuk

Table 1

Climate data for selected localities along the coast of Southwestern Australia[1]

SECTOR	LOCALITY	Climatic Data: Annual rainfall (mm)	Rain days per annum	Annual[2] evaporation (mm)	Mean daily temperature (°C) in summer (January)	Mean max. temperature (°C) in summer (January)	Mean daily temperature (°C) in winter (July)	Mean min. temperature (°C) in winter (July)	Wind[3] in Summer
1	Busselton	838	137	1200	21.2	28.8	12.4	8.1	landbreeze/seabreeze system mainly 0-20km/hr; emanating mainly from SSE & NW respectively
2	Bunbury	881	122	1300	21.9	27.4	12.9	9.1	landbreeze/seabreeze system mainly 0-20km/hr, but up to 20-40km/hr in the northern areas mainly from SE-NE & SW respectively
&	Mandurah	897	121	1500	23.1	28.7	13.4	9.4	
3	Fremantle	775	128	1900	23.0	27.7	13.9	10.2	
4	Lancelin	627	126	2000	23.0	28.7	14.6	10.1	landbreeze/seabreeze system mainly 20-40km/hr mainly from SE-E & S-SW respectively
&	Jurien Bay	519	100	2200	23.0	29.3	14.5	9.6	
5	Geraldton	477	88	2500	25.1	31.6	14.3	9.2	

[1] Data from Bureau of Meteorology 1975
[2] Estimated from evaporation map (Bureau of Meteorology 1980)
[3] See Searle & Semeniuk 1985a.
Only summer wind is considered important in developing onshore aeolian landforms. Onshore wind in winter is usually mild, although periodically punctuated by storms accompanied by rain.

1983). The Safety Bay Sand may have one of several types of stratigraphic relationships with the adjoining stratigraphic units (Playford *et al* 1976, Searle 1978, Semeniuk 1983, Semeniuk & Searle 1985b, Searle & Woods 1987). These relationships are (Fig. 2): Type 1, a sheet of Safety Bay Sand overlies seagrass bank sedimentary deposits, but is detached from Tamala Limestone; Type 2, a ribbon to prism of Safety Bay Sand abuts and encroaches upon Tamala Limestone; Type 3, a ribbon or shoestring of Safety Bay Sand is perched upon and overlies Tamala Limestone in a near coastal setting; Type 4, lenses, ribbons and shoestrings of isolated and detached Safety Bay Sand sedimentary deposits are perched upon and overlie Tamala Limestone; and Type 5, a shoestring of Safety Bay Sand overlies estuarine sedimentary deposits but is detached from Tamala limestone.

The significance of these types of large scale stratigraphic contacts is that each provides a separate geomorphic and hydrologic setting for the Quindalup Dunes. A low relief sand plain situated 2 to 3 to 5m above the water table and overlying a sand aquifer, for instance, provides a different setting to a high relief dune terrain situated 10-30m above the water table and underlain by limestone that has a calcrete capstone. The various stratigraphic types and their distribution with respect to the coastal sectors of Searle & Semeniuk (1985) are illustrated in Figure 2.

There also is a variety of stratigraphic features internal to the Safety Bay Sand; these include: 1) beach/beachridge sheet, overlain by aeolian sand sheets and lenses, which are cross-layered to root-structured to homogeneous (Semeniuk & Johnson 1982); and 2) aeolian sand sheets, lenses and wedges, cross-layered to root-structured to homogeneous, with intercalated soil sheets and local development of calcrete sheet (Semeniuk 1983, Semeniuk & Meagher 1981a, Semeniuk & Searle 1985a).

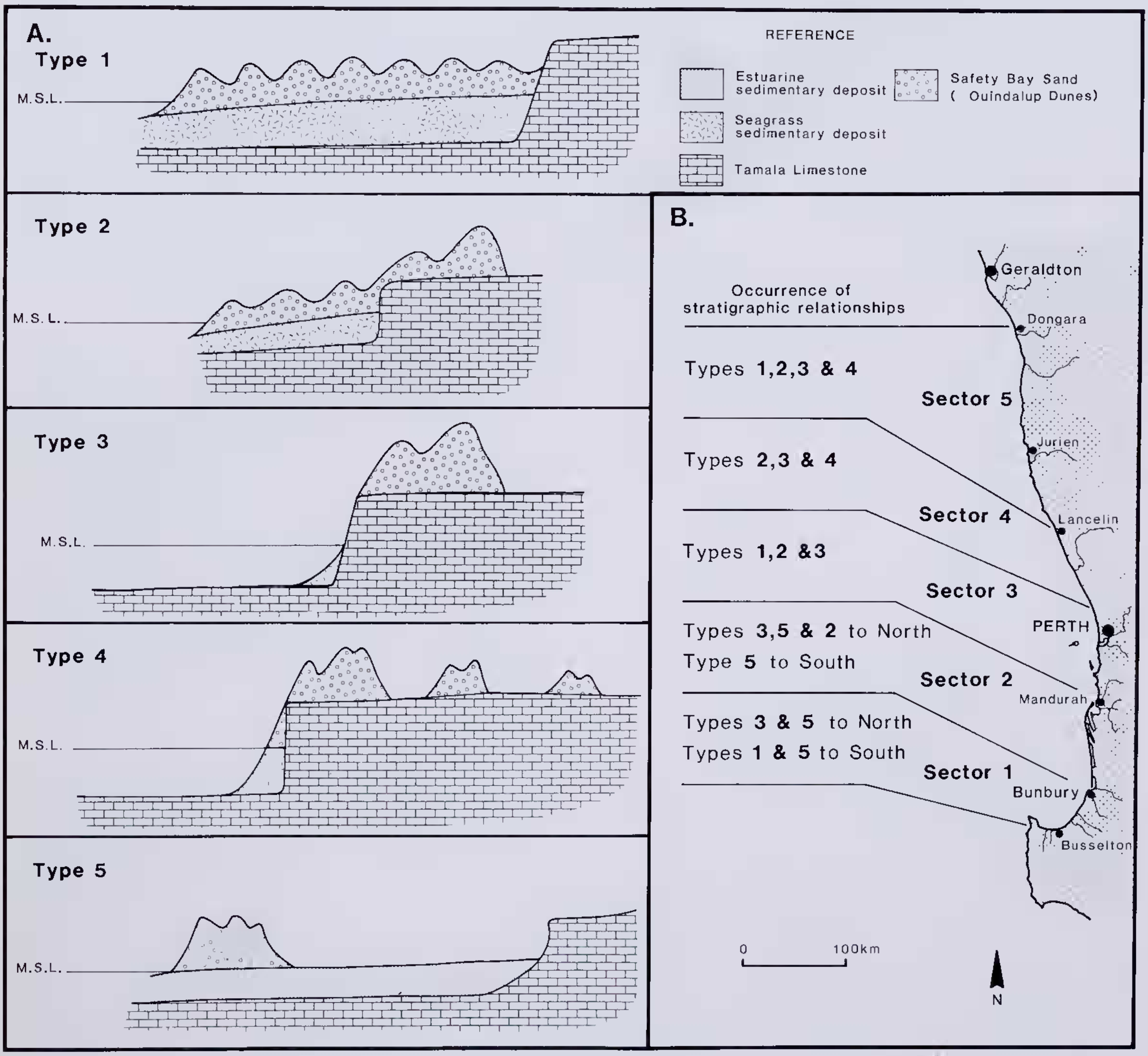


Figure 2 The range of stratigraphic relationships of Safety Bay Sand with adjoining units.

The variety of internal stratigraphic features and lithologies, such as calcretes and buried or intercalated soil sheets, has some relationship to vegetation in that it influences moisture retention and either facilitates or retards vadose water migration. The inter-relationships of calcrete and vegetation have been previously discussed in Semeniuk & Meagher (1981a) and Semeniuk & Searle (1985a).

Soils

The soils of the Quindalup Dunes have been described by McArthur & Bettenay (1960), McArthur & Bartle (1980a,b), Semeniuk & Meagher (1981) and Semeniuk & Searle (1985a). Soils are mostly arenosols (sandy soils) and are developed as pedogenic overprints on a quartzose calcareous, medium to fine grained sand (usually a quartz skeletal lithoclast grainstone, in the terms of Dunham 1962). Degree of soil development is indicated by the amount of humus developed, the degree to which carbonate grains have been leached and the extent of root structuring and bioturbation. The most common soils, listed here in order of developmental maturity and area abundance, are:

thin (<20cm), weakly humified quartzose calcareous sandy soil;
thin (<50cm), humic quartzose calcareous sandy soil;
thick (1-2m), humic quartzose calcareous sandy soil;
thick (1-2m), humic quartz sandy soil.

The soils generally form sheets over the dune terrain and have their thickest development in swales and lowlands. Subsequent landward migration of aeolian sediments may bury a soil profile. Details of soil profiles and soil features as they relate to habitats and vegetation will be presented in future publications.

The results of soil salinity transects are shown in Fig. 3. Generally soil salinity, although initially highest near the shore, does not gradually increase to landward. However, the occurrence of humic soils increases the capacity of soils to retain salt and results in locally high values of salt content. The mean salt content of the soils increases regionally from south to north in response to more intense (salt bearing) onshore winds, more evaporation and the decreased effect of leaching rainfall. However, at any area locally the salt content of soils also increases due to humus content.

In northern areas where deflation flats have been formed close to a water table, indurated carbonate crusts may also be developed on the aeolian sands. These crusts are wide-spread sheets hundreds of square metres in area and up to 30cm thick. These crusts result in localized limestone-like pavement habitats.

Vegetation

The vegetation of the Quindalup Dunes occurs predominantly as a system parallel to the coast (Beard 1976, 1981). Because the Quindalup Dunes occur over a wide climatic gradient in a north-south direction, and may exhibit an east-west variability in landforms and habitats, it may be expected to exhibit regional variation. A gradient is evident in the structure and floristics of the vegetation from south to north. In the southern sectors low forest, woodlands and scrub are the dominant types with *Agonis flexuosa*, *Eucalyptus gomphocephala* and *Acacia* spp. as the main overstory species. In the northern sectors the dominant structural units are scrub and heath, with several species of *Acacia* and *Melaleuca* as the main overstory species.

Although regional changes in vegetation structure and floristics should be gradual, in response to a north-south climatic gradient, this is not strictly the case. The dominant vegetation habitats developed in each of the five sectors identified by Searle & Semeniuk (1985) are distinct from adjoining sectors, and therefore there is not a simple recurring pattern of similar habitats along the entire length of the southwestern coast. Thus the changes in dominant habitat types between the sectors and the climatic gradient along the length of the coast interact to develop a heterogeneous distribution in the structure and floristics of the vegetation units at regional and large scales. At the local scale vegetation also is strongly related to habitat features. Therefore as the habitat types change so does vegetation structure and floristics. Within any given area there will be vegetation response due to factors such as distance from ocean, soil development, position in the landscape and fire history. Furthermore, soil and landscape factors are also related to climate, and altogether produce distinct regional and local patterns in the vegetation of the Quindalup Dune System.

Terminology for geomorphic/habitat units

It is important to compare *similar* geomorphic units or habitats if patterns of vegetation distribution are to be understood at the regional scale through to the local scale. Accordingly, it is necessary to apply a consistent set of geomorphic/habitat terms throughout the Quindalup Dunes.

In terms of vegetation habitats it is necessary only to note the resulting shape of the land surface, and apply a non-genetic term to describe it. This approach is the basis for our choice of non-genetic terminology. Criteria adopted in this paper to describe and name dune landforms are: dune geometry (eg parabolic); relief (eg high, medium, low, undulating, flat); continuity (continuous vs disrupted); and alignment relative to shore (parallel, oblique, transverse)

Geomorphology

A number of authors have described and classified dune landforms (Goldsmith 1985, Cooper 1967, McKee 1979, 1982, Breed & Grow 1979, Davies 1980, Mainguet 1984, Hesp 1984a, Tinley 1985, etc). Most of the terms in these works are non-genetic and based on geometric criteria and, as such, are adopted here. However some terms have been coined in this paper because there were inadequate terms in the literature for the type of landform encountered in this study, or because the only terms available were genetic.

The new terms for dune landforms coined in this paper are *chaots, conical hill residuals, and shore-transverse ridges*. Definitions of terms used are provided in Table 2. Parabolic dunes also have been subdivided into *crescentic*, *attenuated* and *fretted* types. The fretted category is a new form described in this paper. Some of the subdivisions of parabolic dune systems into components of arms, inner face, advancing face and bowl, for purposes of distinguishing habitats for vegetation, also are new. The other terms used are established in the literature but are modified by descriptors to denote features such as relief, continuity and alignment in relationship to the shore. Illustrations of large and medium scale units are provided in Fig. 4.

Some of the new terms in this paper are equivalent, either fully or in part, to those in the literature. This applies to the terms shore-transverse ridges, bowls, and conical hill residuals. Shore-transverse ridge is equivalent to longitudinal dune of Thom (1965), and may be partly equivalent to wind rift dune of Hack (1941) and Mabbut (1977). However, shore-transverse ridge is preferred because the term does not carry a genetic connotation, as wind rift does, and does not imply an orientation with respect to wind direction and origin that is associated with the term longitudinal. The term bowl incorporates the term dune slack of Ranwell (1972), but the former term is preferred because it does not carry implication of wind deflation down to a non-erodable surface such as rock, shingle or wet sand. The

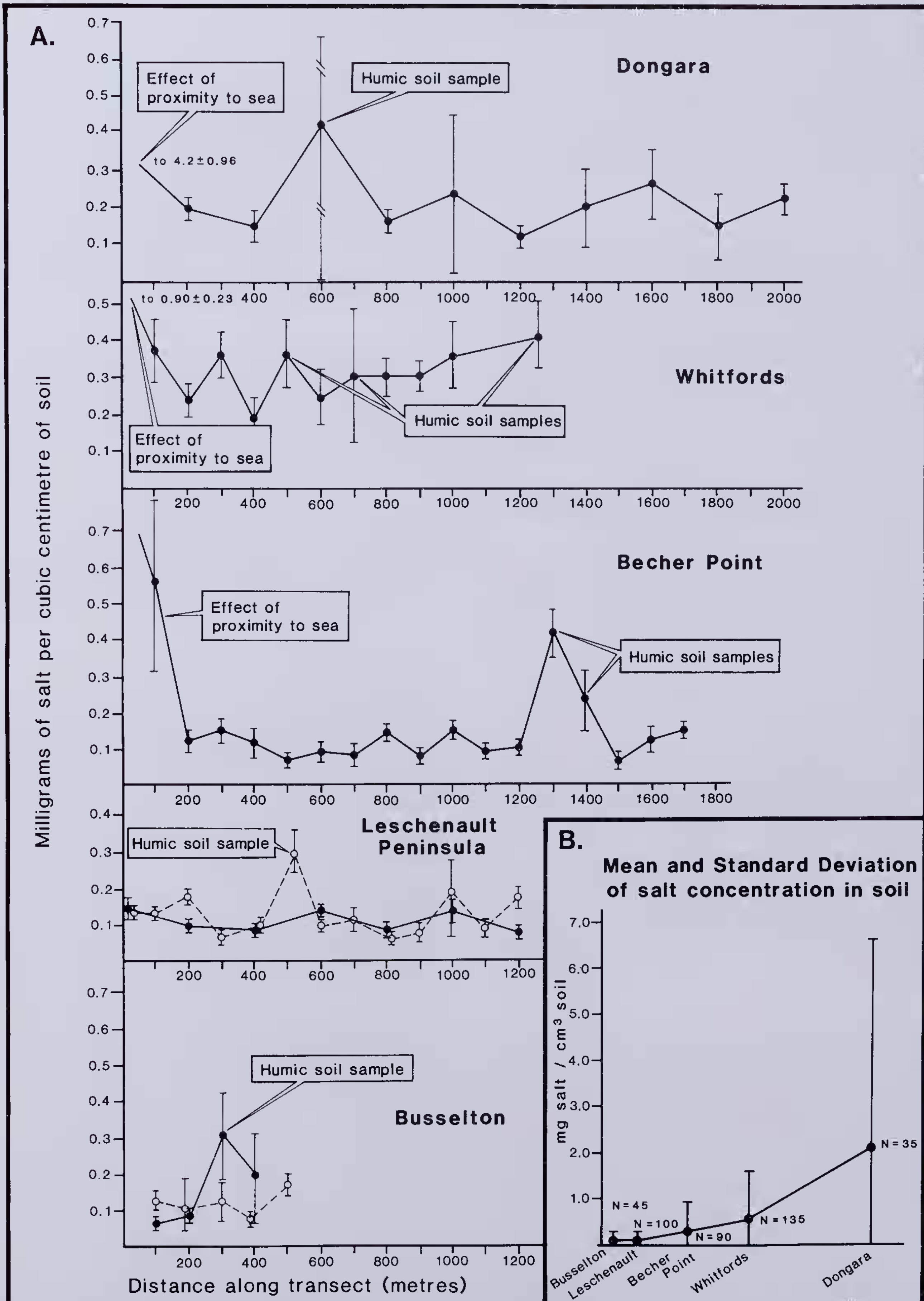


Figure 3 A Salt concentration in soils along transects from shore to hinterland, parallel to dominant wind direction, for each sector (replicate sample n=5).

B Bulk mean salt concentration of coastal dune soils in a subcontinental perspective from Busselton to Dongara.

Table 2

Definition of terms

Geomorphic term	Definition*	Comments
Shoreline dune ribbon	shore-parallel, low relief dune complex with ribbon-shaped plan and cross-sectional geometry; the complex abuts/adjoins the hinterland	a regional to large scale feature
Barrier dunes	shore-parallel, low or high relief, narrow dune complex forming a barrier to lagoon or estuary	a regional to large scale feature
Cuspate beachridge plain	low relief accretionary plain of parallel sand ridges; coastal margin of plain is cuspate; plain is result of coalescence of adjoining cusps	a regional to large scale feature
Cuspate foreland, or cusp	isolated, accretionary sediment body; triangular in plan; composed of low relief to high relief dune complex	a regional to large scale feature; the term cuspate foreland refers to the largest type of cusp (see Bates & Jackson 1980); the term cusp in the literature usually refers to small beach cusps but there is no scale restriction to the term; in this paper there also is no size implication in the use of the term
Perched dunes	shoreward encroaching dune complex of parabolic dunes and sand sheets perched upon and transgressing the upland hinterland limestone terrain; irregular plan and cross-sectional geometry	a regional to large scale feature
Foredunes	shoestring deposit of sand developed by aeolion processes usually as a low ridge immediately landward of beach and seaward of the first high relief-medium relief dune complexes further to landward; may comprise a narrow belt on the sheltered coast of cuspate forelands	subdivision of foredune morphology is provided by Hesp (1984a)
Parabolic dunes	sand dune, u-shaped to spatulate in plan, convex in downwind direction. Three types are recognized based on plan geometry: *crescentic*, which is a short to elongate u-shape; *attenuated* which is markedly elongate to the extent that the dune form consists mostly of parallel arms; and *fretted*, where the arms of the dune have developed subsidiary smaller blow-outs and parabolic dunes. Parabolic dunes are subdivided into components of arms, bowl, advancing face, inner face, conical hill residuals	attenuated parabolic dunes are termed hairpin (Bates & Jackson 1980) and fretted parabolic dunes are *in part* synonymous with compound imbricated parabolic dunes of Tinley (1985)
Chaots	a *chaotic* system of sand hills, mostly conical in shape and of *various sizes and relief*, and associated, mostly circular depressions. The entire chaot system may be low relief, medium relief or high relief. The chaot system itself may be sheet-form or ridge form	this geomorphic term is new as defined in this paper; however the term incorporates erosional as well as accretionary dune forms and is intended to be descriptive not genetic

Table 2

Definition of terms (continued)

Geomorphic term	Definition*	Comments
Shore-parallel ridges	a system of linear parallel sand ridges usually of similar relief (ie low or high) with intervening linear depressions. The ridges may be subdivided into continuous and discontinuous (disrupted) types	these low ridges are also termed "beachridges" in this paper and by others (Woods & Searle 1983)
Shore-transverse ridges	a system of high relief ridges developed transverse to the shore; in specific areas there may be a system of adjacent parallel transverse ridges	the term may be in part synonymous with wind rift dunes of Hack 1941 & Mabbut 1977; these dune forms are not longitudinal dunes
Blowout	small to large trough shaped depression or scour formed by wind erosion. Blowouts are subdivided into the components of floor, walls, and, where vestiges of the original terrain remain, conical hill residuals. The transported sand may form local conical hills or parabolic dunes	Bates & Jackson 1980 use the term "blowout" to refer to the eroded terrain and to the adjoining accumulation of sand, where recognizable, derived from the depression. However in this paper if the derived sand assumes a recognizable parabolic form it is termed a parabolic dune
Undulating plain	low relief plain with broad, gentle undulations	A large to medium to small scale feature
Flat	medium to small scale geomorphic feature com prised of flat terrain	the flat is not obviously linked to any parabolic dune, in which case it would be a bowl; see bowl
Conical hill residual	small to medium scale conical hill left as an erosional residual as the surrounding terrain is scoured away, either in a blowout or within a migrating parabolic dune	the conical hill residual usually has a capping of tenacious vegetation which has determined why the landform remains as a residual
Bowl	flat or slightly concave floor of the inner portion of a parabolic dune; the bowl is contained by the arms and inner face of the parabolic dune	bowls and flats are similar except that bowls are confined by parabolic dune arms; the term is partly synonymous with dune slack, Ranwell 1972
Coppice dune	a conical mound or hummock of sand accumulated around vegetation (Cooper 1967)	these dunes are not common in the study area
Barchans and Barchanoid ridges	intergradational spectrum from small isolated crescentic dunes oriented transverse to wind direction, with a gently convex windward face, concave leeward face and horns pointing downwind (barchans), to ridges, transverse to wind direction, with incipient barchan geometry	these dunes are not common in the study area and usually occur as small-medium scale units on crests and margins of active parabolic dunes
Transverse dunes	linear, strongly asymmetric dune ridge oriented transverse to wind direction with gently sloping windward face and steep leeward face (Bates & Jackson 1980); grades into barchanoid ridge	these dunes are not common in the study area and usually occur as small-medium scale units on crests and margins of active parabolic dunes
Wetland	Wet, waterlogged or inundated flats within the dune terrain	the wetland types are not discussed further in this paper

* of dune geometry regardless of whether dune is mobile, bare, or fixed

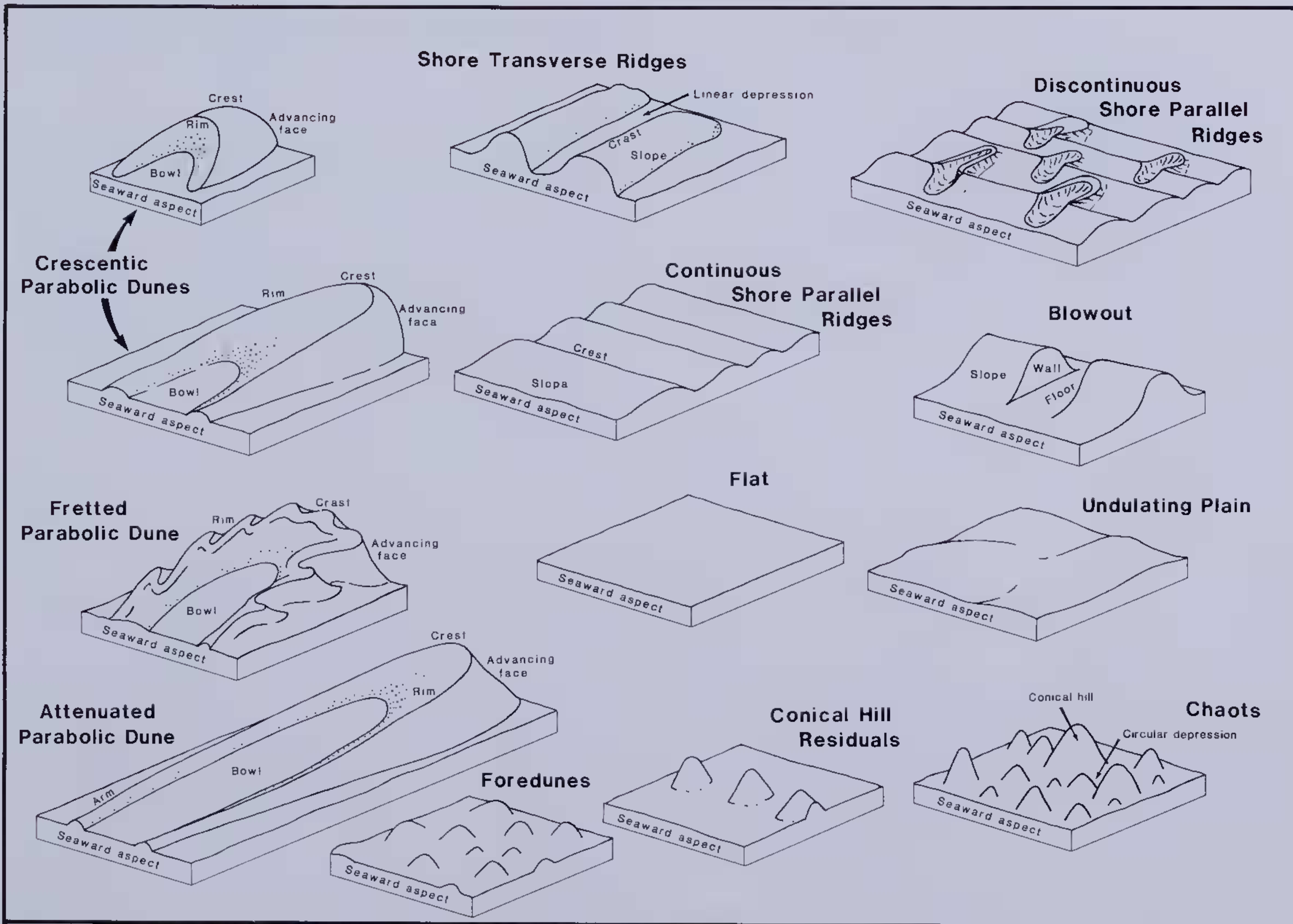


Figure 4 Diagram illustrating the range and geometric features of the most common coastal-dune landforms.

term bowl is intended to describe the geometric form of the concave centre of a parabolic dune system regardless of whether or not its floor lies at a distinct stratigraphic or hydrologic interface. The term flat thus also is partly equivalent to dune slack. The term conical hill residual is preferred to remnant dune of Davies (1980) because it conveys description of a conical shaped remnant .

The descriptive term chaot is applied to a system of dunes whose surface is a chaotic system of conical landforms. The chaotic terrain may be the result of erosion producing conical hill residuals, or the result of erosion and accretion, where accretion has resulted in acute coppice dunes, parabolic dune fronts, and sand sheets. In these terrains with the chaotic system composed of a closely related aggregate of landforms of various origins it is difficult to separate accretionary and erosional components for classification. The term chaot thus is intended to address this situation descriptively.

The use of terminology such as "vegetated dune" or "fixed dune" as a geomorphic unit as distinct from "bare and mobile dunes" or "non-vegetated dunes" is widespread in the literature (Goldsmith 1985) and in the past also has been applied to the coastal dunes of Western Australia (Semeniuk & Meagher 1981b). This terminology for geomorphic units based on absence or presence of vegetation has been rejected in this paper. Dune landforms are described and termed according to their geometry, relief and configuration, and the presence of vegetation should have no part in primary terminology of geomorphology and habitats. Accordingly, dunes such as parabolics that vary from actively-mobile bare forms, to recently-fixed vegetated forms, through to older, fixed vegetated forms, may comprise similar components and geometry, and as such are simply termed parabolic dunes. The absence, presence, or range of vegetation cover is viewed as varying stages of plant colonization on a dune habitat. The description and nomenclature of the various stages of plant colonization through time is viewed as the realm of plant ecology and not geomorphology.

Habitats

Vegetation responds to variability in landform and edaphic features at the small scale, and it is the small scale geomorphic unit that forms the basic habitat unit. Thus the range of small scale features of the various large to medium scale geomorphic units are treated as the habitat types of the Quindalup Dunes. However, geomorphology alone does not determine whether a given terrain is a suitable habitat for the various species of vegetation. Other features of the habitat, such as seaward aspect, landward aspect, north (sun-facing) aspect, height relative to the water table, salinity of vadose and phreatic water, and extent of soil development also need to be considered. The smallest scale of geomorphic features provides the basis upon which to overlay the other edaphic features.

The amount of detail required to describe habitats for vegetation necessitated subdividing the landforms of the coastal dunes into smaller and smaller units to arrive at the scale at which the vegetation responds. Accordingly, there is a range of geomorphic terminology applicable at the various scalar frames of reference (Table 3). The range of smaller scale variability in geomorphology can result in a mosaic of small scale vegetation responses. Thus shore-parallel, low, continuous ridges provide one type of habitat distribution, and shore-parallel, low, disrupted ridges provides a more complex habitat system.

In this paper, the term habitat is used interchangeably with small scale geomorphic unit and differentiation of habitats beyond this scale was not undertaken. The basic geomorphic and habitat unit, however, will be differentiated on other edaphic criteria in future habitat and vegetation studies.

Geomorphic processes and the development of coastal dune morphology

Whereas the approach adopted here to describe and name geomorphic units of the coastal dunes in the first instance has been based on non-genetic precepts, it is nonetheless worthwhile to describe briefly the origin and genetic interrelationships of aeolian landforms to provide an understanding of their temporal and spatial relationships. The importance of recognizing the genetic category to which a geomorphic unit belongs is that habitats can be broadly viewed in terms of their

Table 3

Geomorphic units present at each scale of mapping

Regional scale	Large scale	Medium scale	Small scale
• Shoreline dune ribbon • Barrier dunes • Cuspate beachridge plains • Cuspate forelands, or cusps • Perched dunes	• Foredunes • Parabolic dunes crescentic attenuated fretted • Chaots low relief medium relief high relief • Shore parallel ridges • Shore transverse ridges • Blowout • Undulating plain	• Foredunes • Parabolic dunes crescentic attenuated fretted • Components of parabolic dunes arms bowl inner face advancing face conical hill residual • Chaots low relief medium relief high relief • Shore parallel ridges continuous low relief continuous high relief disrupted low relief disrupted high relief • Shore transverse ridge ridge slope swale crest • Barchans • Barchanoid ridges • Transverse dune • Coppice dune • Flat • Blowout • Undulating plain	• Hill or ridge slope • Linear depression • Circular depression • Conical slope • Crests

longevity, stability and dynamics which then can be related to interpretations about the stage of succession that a vegetation complex has achieved, recognizing that other processes such as fire also might influence vegetation succession.

The variety of coastal dune landforms can be categorized into 4 genetic/process-related types: accretionary; erosional; mobile; and degraded. These types may be expressed at the large, medium or small scales. In addition the various types may be related in time and space (*eg* an eroding dune supplies sand to a mobile dune which, once mobilized, uses the store of sand in its migration. There also may be smaller scale overprinting of one dune form on another. For example, a medium scale system of shore-parallel, continuous, low ridges (accretionary dune) may be overprinted by small scale blowouts (erosional form) to develop small scale shore- transverse parabolic dunes (mobile dune). Thus the original shore-parallel system of continuous low ridges is transformed into a system of shore-parallel disrupted low ridges. This sequence has been described previously, in part, by Ranwell (1972).

The main large to medium scale geomorphic units occurring within the four genetic coastal dune landform categories are:

- *accretionary types*: foredunes; coppice dunes; shore-parallel ridges (beachridges); chaots;
- *erosional types*: blowouts; flats;
- *mobile types*: parabolic dunes; barchans; barchanoid ridges; transverse dunes;
- *degraded types*: chaots; undulating plain; shore-transverse ridges.

Further accretion, erosion, degradration, or migration of these basic landform types results in the proliferation of medium and small scale geomorphic units. The relationships and evolution of one landform into another are diagrammatically illustrated and described in Fig. 5.

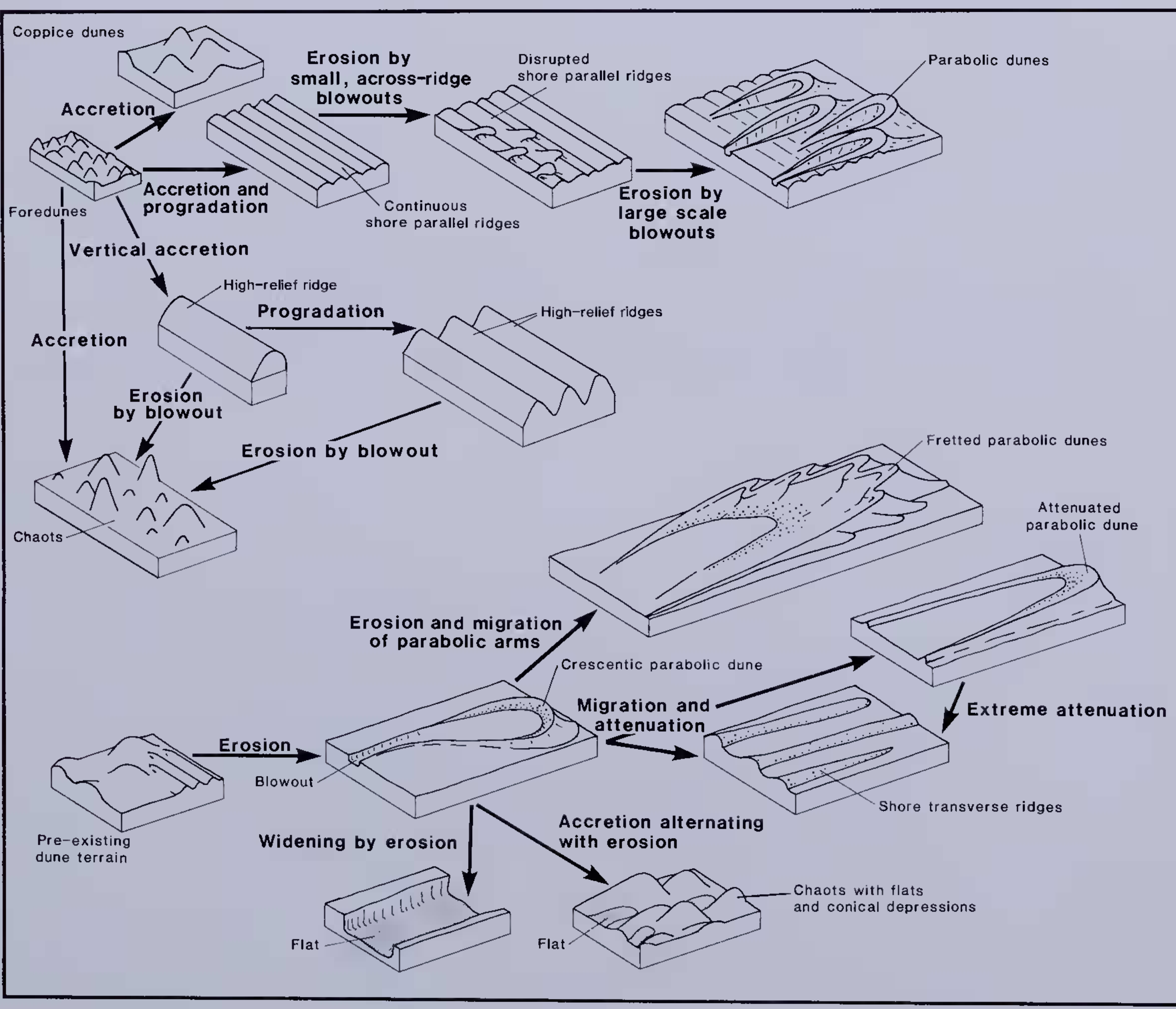


Figure 5 Inter-relationships between the various geomorphic units of the Quindalup Dunes, and the process by which one landform develops into another.

Geomorphology and habitats of the Quindalup Dunes

The coast adjoining the Swan Coastal Plain has been divided into five sectors by Searle & Semeniuk (1985). Each is distinguished by a unique combination of modern onshore and offshore geomorphology, coastal processes and Holocene sediment accumulations. The sectors from south to north are: Geographe Bay Sector; Leschenault-Preston Sector; Cape Bouvard-Trigg Island Sector; Whitfords- Lancelin Sector; and Wedge Island-Dongara Sector.

Each sector has a distinct array of Quindalup Dunes based on the criteria of: 1) total external geometry (*eg* beachridge plains, cuspate forelands or cusps, using the definition in Bates and Jackson (1980) that a cuspate foreland is the largest type of "cusp"); 2) internal array of landforms (linear depressions (swales) and ridges, parabolic dunes, blowouts); 3) dynamics of landform (prograding strandline, actively migrating parabolic dunes, vertically degrading ridges); and 4) relative relief.

The Quindalup Dunes within each sector are described below in terms of both geomorphology and vegetation habitats. At the regional scale the different shapes of the Quindalup Dune terrain can be recognized as 1) shoreline dune ribbon, 2) barrier dune, 3) cuspate beachridge plains, 4) cuspate forelands, or cusps, 5) perched dunes. Representative maps showing distribution of typical landforms/habitats within each sector are provided in Figs 6-11. A summary of the essential geomorphic features of the Quindalup Dunes in each sector is provided in Fig. 12. A summary of the main habitats encountered in each sector is provided in Table 4.

Table 4

Dominant habitats occurring in each of the sectors

Sector	Dominant regional scale units	Dominant medium scale geomorphic units	Dominant habitat types
1	E-W oriented, low, linear barrier of, and a N-E oriented shoreline ribbon of parabolic dune	undulating plain	• undulating plain
		shore-parallel ridges	• linear depessions • ridge slopes, seaward and landward aspect • ridge crests
2	N-S oriented linear high barrier dune and northern section of shoreline ribbon of parabolic dunes	attenuated parabolic dunes	• bowl • inner face • advancing face • crest • conical hill residuals
		blowouts	• blowout floor • blowout wall
		shore-transverse ridges	• ridge slopes, north and south aspect • ridge crests • linear depressions
3	extensive cuspate low beach ridge plain	attenuated parabolic dunes	• bowl • inner face • advancing face • crest • conical hill residuals
		chaots	• crests of chaots • slopes of chaots • circular depressions
4	large scale cuspate forelands (or cusps) and perched parabolic dunes	fretted parabolic dunes	• bowls • inner face • advancing face • crest • conical hill residuals
5	large scale cuspate forelands (or cusps) and perched parabolic dunes	attenuated parabolic dunes	• bowl • inner face • advancing face • crest • conical hill residuals
		fretted parabolic dunes	• bowls • inner face • advancing face • crest • conical hill residuals
		shore-parallel ridge systems	• linear depressions • ridge slopes, seaward & landward aspects • ridge crests

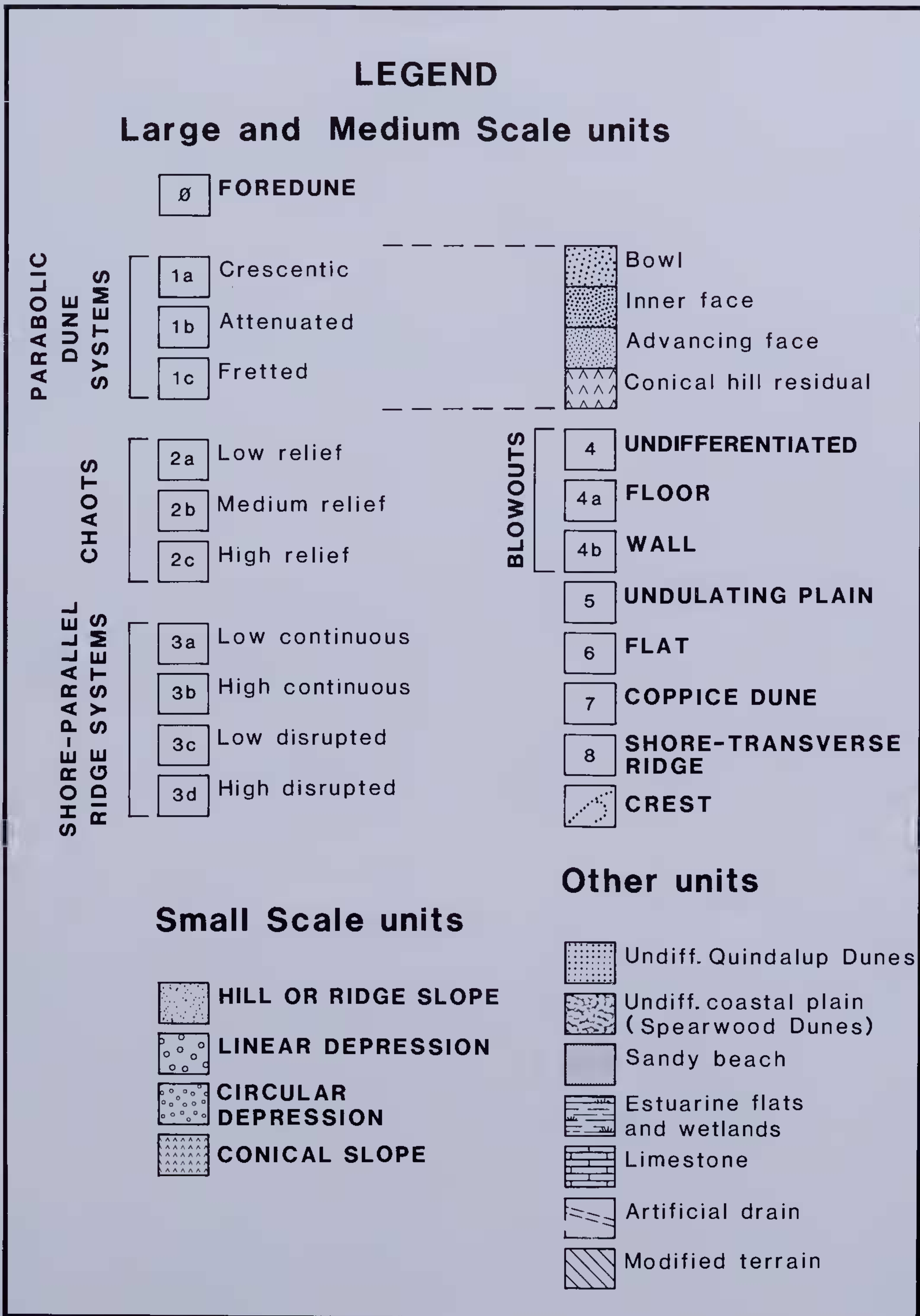


Figure 6 Legend to be read in conjunction with Figures 7-11.

Geographe Bay Sector

Regional and Large Scale Geomorphology

Geographe Bay is a broad, 100km wide, north-facing embayment at the southern end of the Rottnest Shelf. The Quindalup Dune zone is simple and consists, in the central portion of the sector, of a low barrier dune plain which forms a narrow band (average 500m wide), and in the northeast portion, of a shoreline ribbon comprised of parabolic dunes. Along the seaward edge there are beaches, beachridges and low foredunes. Long term Holocene sediment accretion has resulted in progradation of the shoreface along a broad front, generally maintaining the arcuate bay form and developing a beachridge ribbon peripheral to the bay (Searle 1978, Searle & Semeniuk 1985). The development of successive beachridges during coastal progradation has impeded the natural drainage from the hinterland, resulting in the development of elongate fresh to brackish lagoons and inlets in and behind the ridges. In the short term, geologically, the coast has undergone local realignment with development of small to medium scale accretionary cuspate shoreline and erosional scallops that alternate in time and space along a net progradational shore (Paul & Searle 1978).

Medium and small scale geomorphology

An undulating plain dominates the Quindalup Dunes in this sector, but there are also multiple sand ridges, each usually less than 1m high, but up to 5-6m high, and 50m wide, and corresponding linear depressions (swales) and wetlands. There are no blowouts and parabolic dunes in the central portion of the sector, and the Quindalup Dune morphology is essentially similar throughout this portion of the sector. Toward the northeast parabolic dunes and blowouts are present and increase in number as the coast swings to a northerly alignment.

Habitats

The main habitats within the Quindalup Dunes are undulating plains with low and relict ridges, comprised of crests and slopes and depressions. All habitats are of relatively low relief and consequently depth to the water table is usually less than 3-5m. Humic soils are commonly developed on the aeolian landforms throughout this sector.

Leschenault-Preston Sector

Regional and Large Scale Geomorphology

The Leschenault-Preston Sector extends about 80km in a northerly alignment. The Quindalup Dune zone is characterized by an extensive linear, narrow, barrier dune system (some 20-30m high and 0.5-2.0km wide) with its accompanying lagoons (Semeniuk & Meagher 1981b). The barrier is actively retrograding to the east by parabolic dunes and encroaching onto the lagoon environments, and its seaward face is generally undergoing net erosion (Semeniuk 1985). Staggered dune advances in the past several thousand years to the present has resulted in an irregular encroachment of the barrier into the barred lagoon. The current coastal landforms of barrier dunes, segmented lagoons and inlets reflect this history.

Medium and small scale geomorphology

The barrier is dominated by blowouts and eastward migrating attenuated parabolic dunes with their accompanying arms and bowls. These are in various stages of geomorphic degradation and fixing by vegetation. There also are undulating plains (geomorphically degraded dunes), and shore-transverse ridges (= arms of former parabolic dunes). Along the seaward edge of this barrier there are beachridges, foredunes and cliffed dunes.

Habitats

The main habitats are those associated with parabolic dunes, blowouts and undulating plains. Much of the terrain is of high relief, situated well above the water table. Crests and slopes, depending on aspect, type of vegetation cover and stage of vegetation succession, are covered either with minimal humic soil or with moderately developed humic soil. The undulating plains are situated within 1-3m of the water table and are underlain by thick humic soil and a calcrete sheet. The dune landforms are of various ages and in various stages of geomorphic degradation, and accordingly support vegetation at different stages of succession.

Cape Bouvard-Trigg Island Sector

Regional and Large scale geomorphology

The Cape Bouvard to Trigg Island Sector extends over 100km in a north to northwesterly alignment. This sector is characterized by complex nearshore bathymetry and discrete cells of Holocene sediment accretion reflecting net, long term, coastal progradation (Searle 1984, Woods & Searle 1983). The Quindalup Dunes mainly form an extensive low cuspate beachridge plain up to 10km wide. They are developed as a beachridge/dune cover to a Holocene sequence of seagrass sedimentary deposits that have extended from the hinterland towards an offshore limestone barrier. The beachridge/dune plain also has extended seaward, linking with emergent remnants of an offshore limestone ridge to form tombolos and cuspate forelands. The resultant Quindalup Dune morphology is well marked by beachridge accretion lines showing successive shorelines. Intermittent erosion, or cessation in progradation, has developed localized blowouts and parabolic dunes which may appear along a specific former shoreline trend. At present, the five major bank and cuspate foreland structures within the sector represent various stages of an evolutionary process from a submarine lobe to fully-emergent cuspate plain stage (Searle 1984, Searle & Semeniuk 1985).

Medium and small scale geomorphology

Multiple parallel sand ridges, 1-3m high and up to 50m wide, and associated depressions dominate the terrain. However, there also are local areas of blowouts and associated parabolic dunes (up to 20-30m high), bowls, wetlands, and residual conical sand hills. The seaward zone contains low foredunes to steep foredunes, beachridges, coppice dunes and locally, cliffed dunes.

Habitats

The linear crests, slopes and depressions associated with the low parallel sand ridges (or beachridges) are the dominant habitats in this sector. These habitats are situated within 3-5m of the watertable. Humic soils are developed over the terrain to a moderate extent, and more particularly in depressions between the ridges. The occasional parabolic dunes in this area are habitats of high relief and the crests and slopes of these geomorphic units are situated >5m above the watertable, while flats and bowls have been developed to within 1m of the watertable.

Whitfords-Lancelin Sector

Regional and Large scale geomorphology

The Whitfords-Lancelin Sector extends 100km in a north-northwestly alignment. The coast consists largely of eroding rocky shores and pocket beaches interspersed with straight, beached coasts backed by high and perched dunes. Locally, isolated large scale dune-topped sandy promontories extend up to 800m seawards (*cf* Semeniuk & Searle 1986). These cuspate forelands in the long term are either accretionary or slowly eroding. The Quindalup Dunes are restricted to 1) a thin ribbon

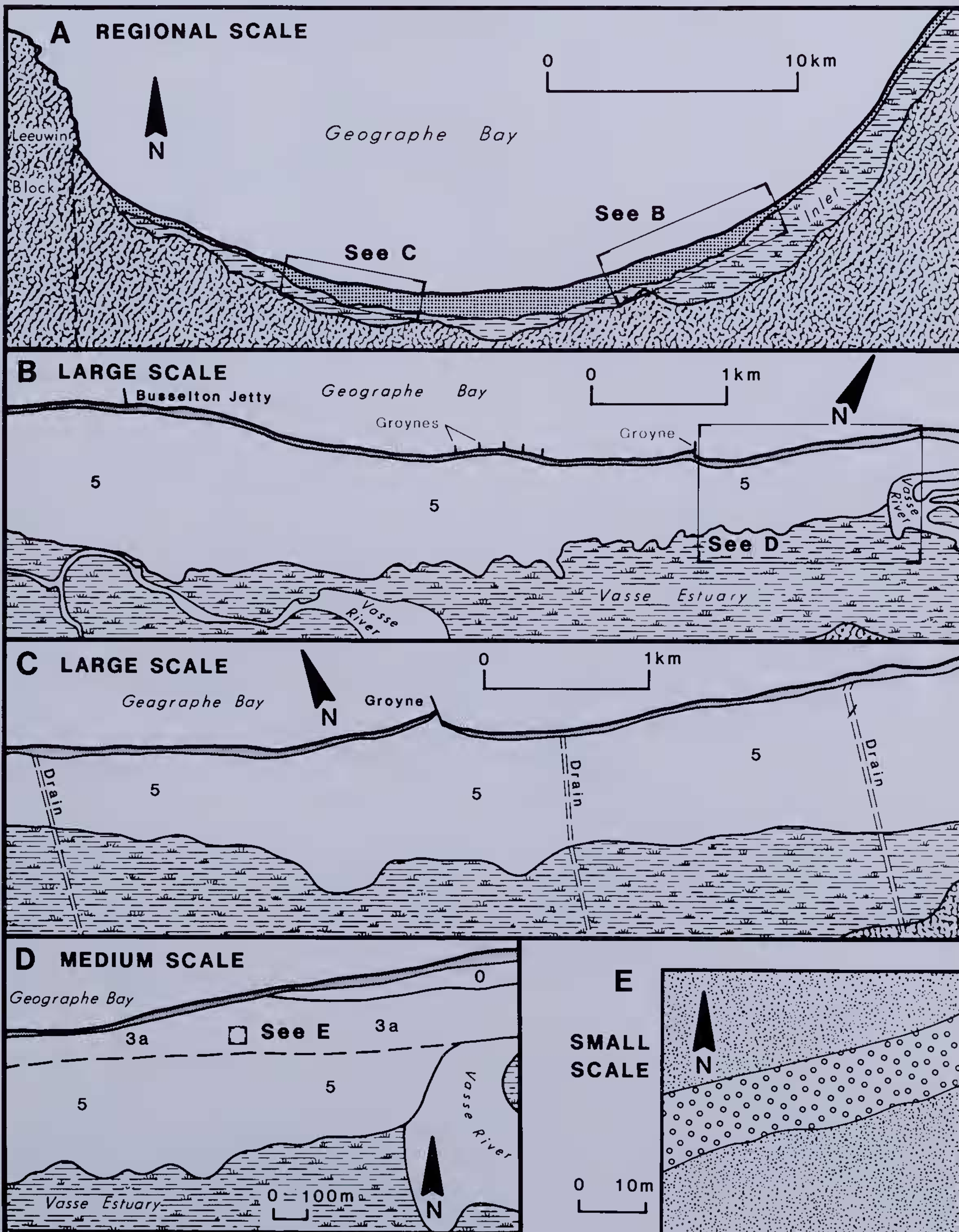


Figure 7 Geomorphic features of the Quindalup Dunes typical of Sector 1. Location of area shown in Fig. 1.

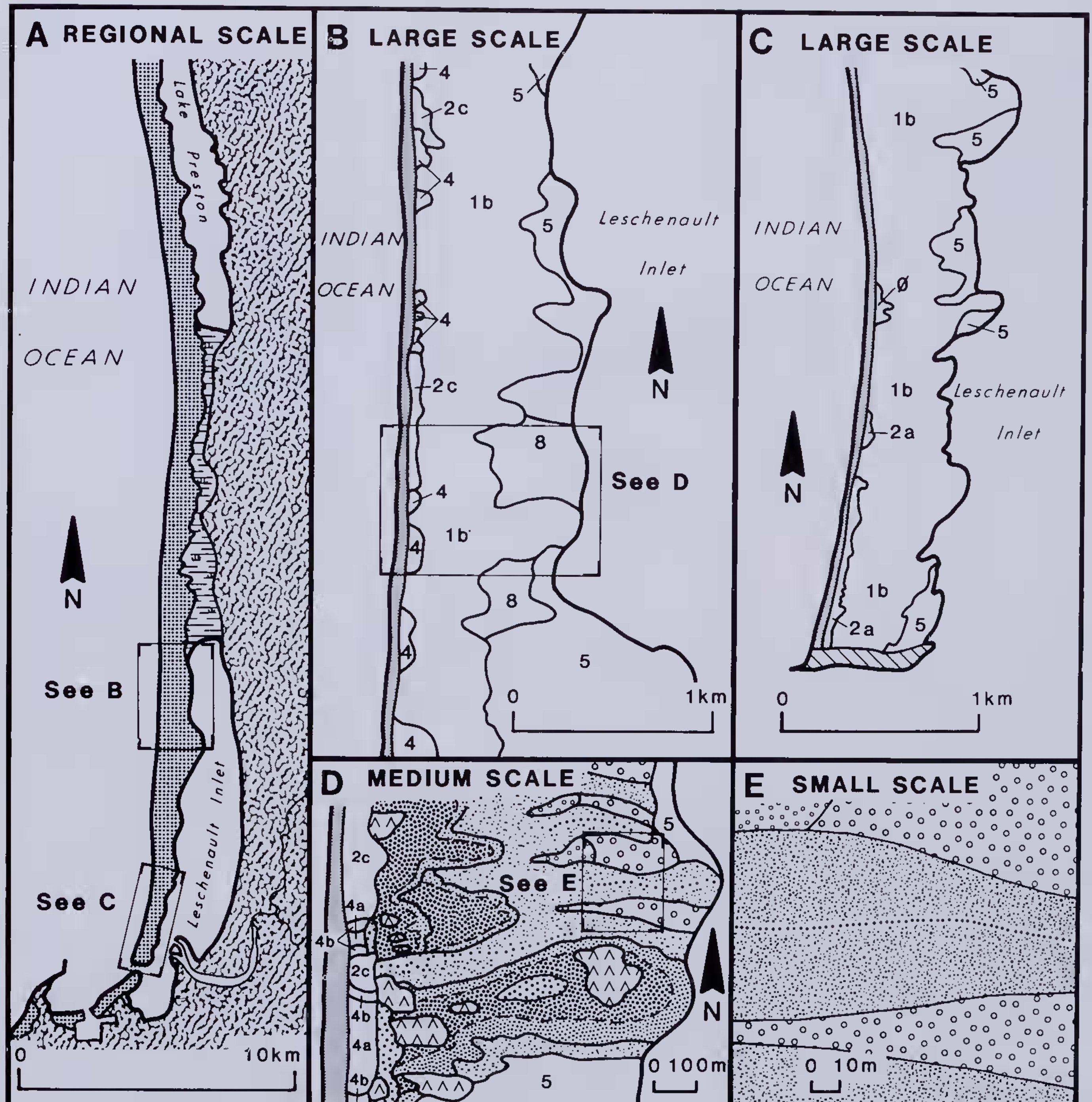


Figure 8 Geomorphic features of the Quindalup Dunes typical of Sector 2. Location of area shown in Fig. 1. Note that some units listed as small scale in the legend (Fig. 6) are also evident in the medium scale maps.

along the rocky shore, 2) small systems of perched dunes (landward advancing parabolic dunes encroaching over the Spearwood Dune terrain) at sites of the large pocket beaches and 3) terrains of the large scale cuspate forelands wherein blowouts and parabolic dunes are dominant, or beachridge plains are present.

Medium and small scale geomorphology

The strandline is dominated by rocky shores, but pocket beaches have beach ridges, low foredunes and (locally) cliffed dunes. Dunes perched on the limestone hinterland tend to be linear chaots or high relief ridges; they are parallel to the shore and tend to be high relief and well-vegetated. Inland, the perched dunes are either chaots or parabolic dunes. The parabolic dunes are the stabilized forms emanating from large blowouts, and they are uniformly oriented to the prevailing onshore winds. Locally, on the discrete large-scale cuspate forelands there is a complex system of overlapping and detached dunes with beachridges and swales, parabolic dunes, conical residual hills and wetlands.

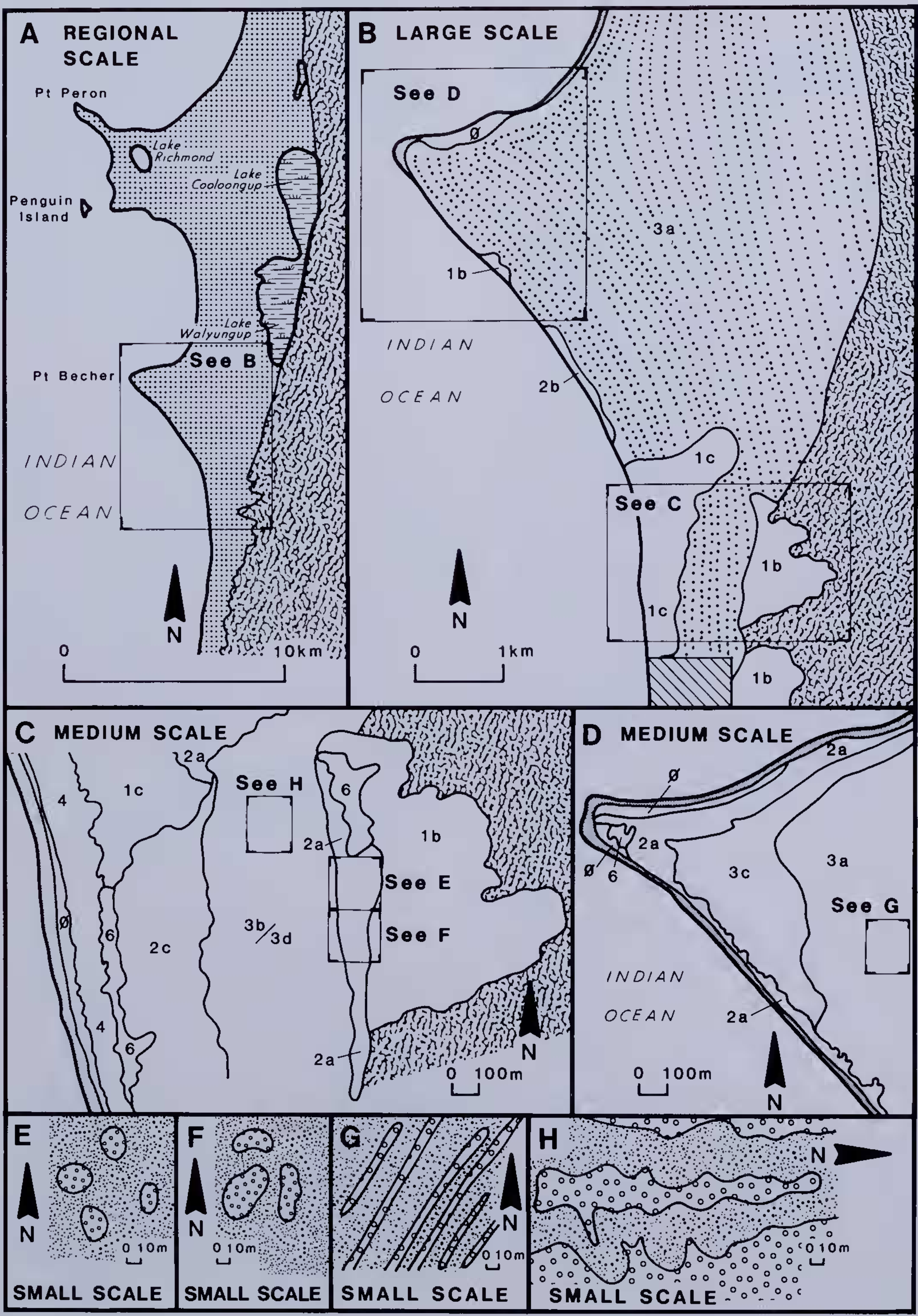


Figure 9 Geomorphic features of the Quindalup Dunes typical of Sector 3. Location of area shown in Fig. 1.

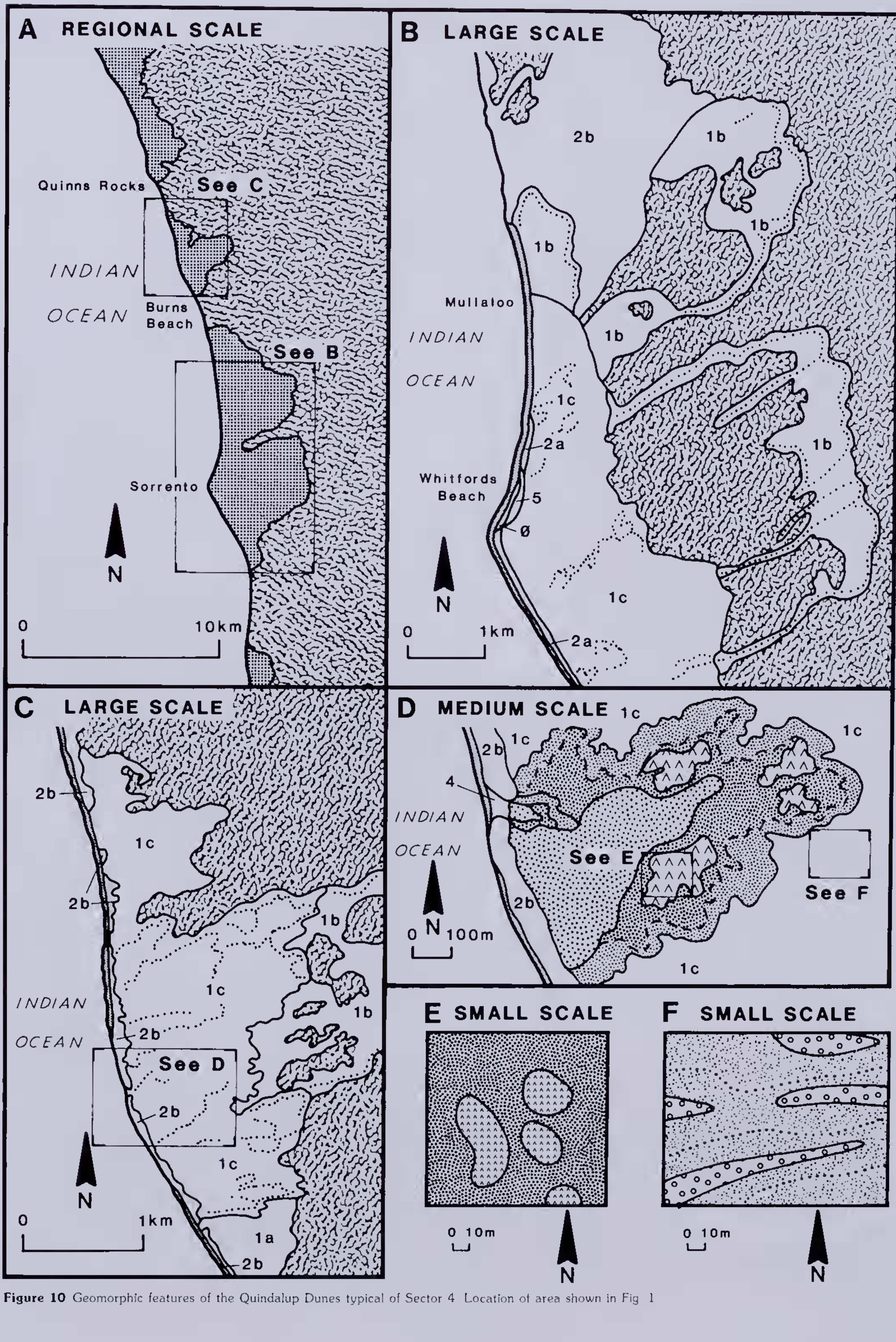


Figure 10 Geomorphic features of the Quindalup Dunes typical of Sector 4. Location of area shown in Fig. 1

Habitats

Parabolic dunes, chaots and blowouts dominate this sector, and the associated habitats of crests and slopes (with varying development of humic soils) are situated high above the water table and may overlie limestone with calcrete capstone. The wind-excavated bowl or flat areas are relatively closer to the watertable but are still elevated. In some places these deflation zones expose underlying limestone such that a limestone pavement habitat becomes exposed as an inlier within the parabolic dune system.

The habitats of the large scale cuspate forelands are slopes, crests and swales of the beachridge plains, and are all situated low in relationship to the watertable. The slopes, crests and flats/swales/bowls associated with parabolic dunes and chaots, are all high relief structures situated >5m above the watertable.

Wedge Island-Dongara Sector

Regional and Large scale geomorphology

The sector from Wedge Island to Dongara extends 180km in an approximately northerly alignment. The coastal geomorphology consists mainly of large erosional scallops into the Pleistocene limestone as well as discrete, accretionary, cuspate forelands which are net-progradational forms (Woods 1983, Hesp 1984b). The rocky coastline is slowly eroding and contains numerous small pocket beaches, and is interspersed with straight to gently arcuate beached coasts. The dune terrains adjacent to the coast are perched dunes and form a discontinuous and irregular high relief ridge, or system of chaots. Markedly attenuated mobile dunes (oriented NNE) and old vegetated parabolic dunes exhibit an alignment between about 010° and 030°. Elongate, roughly shore-parallel wetlands (lagoons or saline marshes) may be developed in the coastal dune terrain.

The coastal morphology of this sector reflects the decline in shelter afforded by the offshore bathymetry and the increase in onshore development of NNE migrating dunes. In the northern parts of the sector, the coast is devoid of prominent cuspate forelands, which reflects the lack of offshore bathymetric features for protection.

Medium and small scale geomorphology

Markedly attenuated parabolic dunes dominate the terrain. Thus there are successive parabolic dune arms oriented N to NNE. The bowl areas are vegetated or have developed into wetlands. On the accretionary cuspate forelands there are multiple beachridges 3-5m high and up to 50-100m wide, with associated swales. Interspersed through the beachridge plain there are blowouts and parabolic dune systems aligned along specific former shorelines. These contain parabolic dunes and bowls. The strandline has beaches, beachridges and low foredunes.

Habitats

Parabolic dunes and blowouts dominate this sector with the concommitant development of the habitats of crests, slopes and bowls. These habitats are situated 5-10m above the watertable with varying development of weakly humic soils. Also present are low beachridge plains with development of crests, slopes and swales situated within 5m of the water table. In local areas there are habitats of extensive limestone-like crust pavements.

Discussion

The regional variability of geomorphology of the Quindalup Dunes, its use in comparative vegetation studies, and its significance to conservation of landforms and habitats are discussed below.

Regional variability of geomorphology

Small scale habitats are determined by the geomorphic processes that are now operating or have operated in the region. Each sector is identifiable because of its distinct suite of coastal landforms and its location in the climate gradient, and it is axiomatic that habitats for vegetation will have developed as a result of those processes peculiar to a given sector.

It is apparent, for instance, that the coastal evolutionary processes of Sectors 2,3 and 4 are markedly different. Sector 2 contains a retrograding barrier dune system and the entire terrain has developed by long term retrogradational dynamics. Sector 3 contains a progradational plain formed by long term net accretion of shoreline sediments to develop a successive series of parallel low beachridges. Sector 4 contains slowly eroding limestone shores and associated pocket beaches, together with the local sedimentary cuspate accumulations in the energy shadow of offshore islands/ reefs, and presents yet another suite of coastal landforms determined by the processes operating in that sector.

Clearly, a variety of landforms exist across and along, the extent of the Quindalup Dunes, and that each sector to some degree contains a suite of coastal landforms unique to that sector. Thus while there is a common thread in the occurrence of some landforms (*eg* beachridges, and foredunes), other specific landforms may occur exclusively or mainly only in a given sector. However, even if a given landform may occur in several sectors, its dynamic morphology may vary regionally. For instance parabolic dunes appear virtually in every sector, but they are most abundant in Sectors 2, 4 and 5 and are most active only in Sectors 2 and 5. Sector 4 contains a predominance of fixed parabolic forms; Sector 5 contains a proportion of active and relict parabolic dunes, but they are incomparable to those in Sector 2 because they are highly attenuated and are associated with much more extensive bowls.

In terms of landform complexity and heterogeneity, the Quindalup Dunes of Sectors 4 and 5 exhibit most variability. There are cusps, perched dunes, parabolics, blowouts, beachridge plains, chaots etc. Sector 1 exhibits least variability probably as a result of the relatively low energy progradational setting, as well as the less intense wind system (resulting in little or no aeolian remobilisation), and higher rainfall (resulting in more marked geomorphic degradation). Sector 3 with its beachridge plain and occasional lines of blowouts and parabolic dunes also exhibits minimal heterogeneity. Sector 4 exhibits moderate landform complexity with its ranges of blowouts, parabolic dunes, plains, shore- transverse ridges etc.

Comparative vegetation studies

The geomorphic framework presented above provides a reference base for future studies of vegetation of the Quindalup Dunes. This framework should enable future workers to allocate vegetation associations (or vegetation complexes) to more specific geomorphic or habitat settings; the framework should also provide for more realistic comparisons between vegetation complexes of widely dispersed localities, and should enable trends in the variation of species distribution in the region, as reflecting variation in the species pool, to be determined. The absence/presence of a given species can then be related either to the absence/presence of an appropriate habitat or to external factors such as climate.

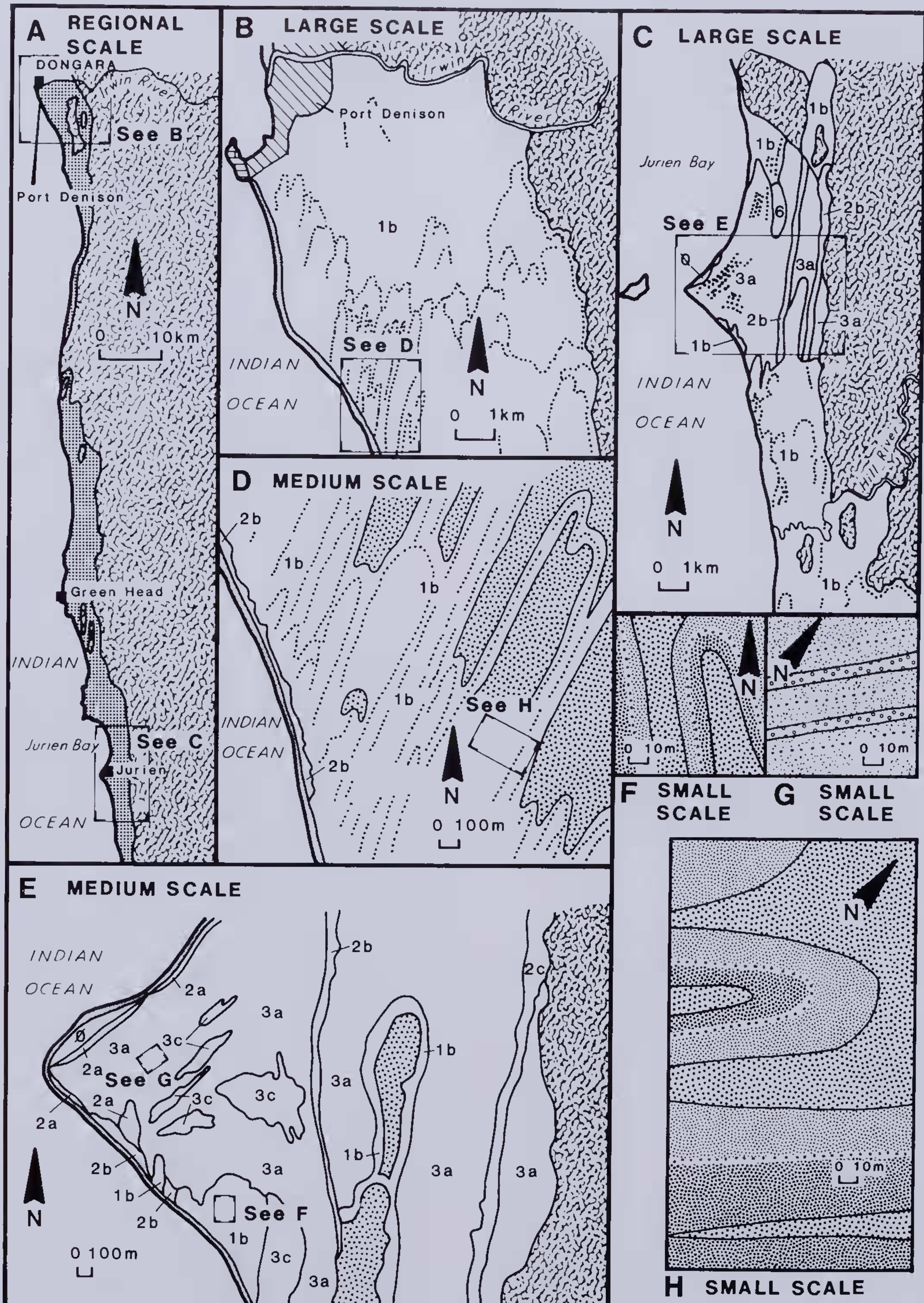


Figure 11 Geomorphic features of the Quindalup Dunes typical of Sector 5. Location of area shown in Fig. 1.

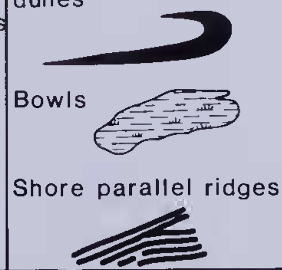
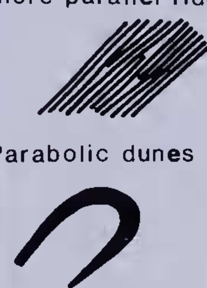
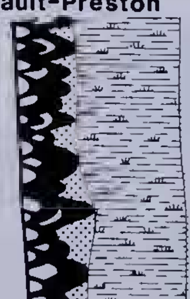
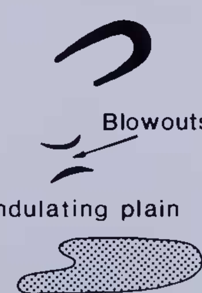
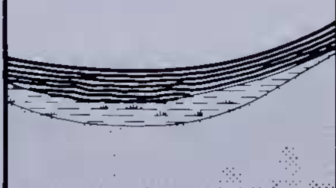
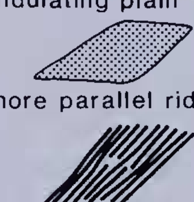
Sector	Dominant Coastal Process	Continuity of Coastal Dunes	Dominant Land Form (plan)
Wedge Island-Dongara 	Limestone coast retreat and landward dune encroachment alternating with areas of coastal progradation in cusps	Discontinuous in discrete accumulations connected by thin ribbons	
Whitford-Lancelin 	Limestone coast retreat and landward dune encroachment alternating with areas of coastal progradation in cusps	Discontinuous in discrete accumulations connected by thin ribbons	
Cape Bouvard-Trigg Island 	Shoreline progradation and development of beachridge plain	Continuous extensive cuspate plain	
Leschenault-Preston 	Barrier retreat and development of blowouts and parabolic dunes	Continuous linear high-relief ridge	
Geographe Bay 	Shoreline progradation	Continuous arcuate low-relief ribbon	

Figure 12 Summary of key features of the Quindalup Dunes in each sector. In this figure the term cusp refers to the large scale coastal cusps (=cuspate forelands).

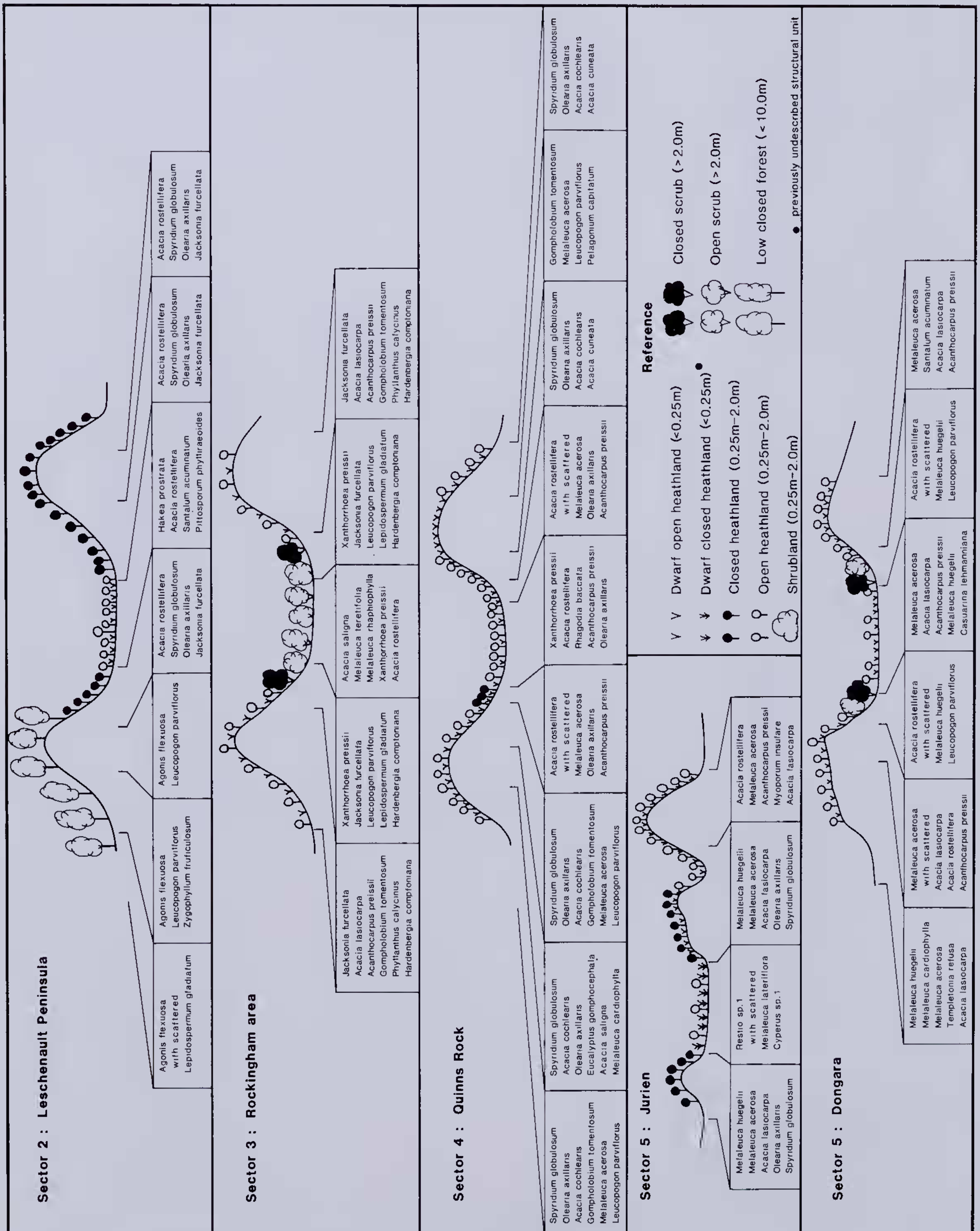


Figure 13 Cross section and vegetation transects through parabolic dunes in sectors 2-5 to illustrate habitats and vegetation structure and floristics. The species noted for each dune habitat represent the dominant species in terms of numerical and/or structural dominance. Vegetation structure terminology modified after Specht 1981.

An example of a vegetation study in a specific geomorphic unit/habitat is provided here to illustrate the suggested manner in which comparative vegetation studies may be undertaken in a regional to subcontinental system. Large scale to medium scale geomorphic units such as parabolic dunes that are common to a majority of coastal sectors were chosen as a basic unit. The vegetated parabolic dunes of Sectors 2, 3, 4 and 5 were studied. The parabolic dunes were subdivided into habitats of crest, slope, toe (= interface between slope and bowl/flat), bowl/flat, and the vegetation was described in terms of structurally or numerically dominant species and vegetation structure for each habitat. The results are presented in Fig. 13.

These results are only preliminary but serve to illustrate that there are significant changes in structure and/or floristics of the Quindalup Dunes between a similar habitat setting within the same sector and from sector to sector. The conclusion underscores the need to compare vegetation from similar geomorphic settings and habitats, when assessing the regional significance of flora. Conversely, it is also obvious that if adjoining sectors have markedly different suites of geomorphic units and habitats then the vegetation complexes of those adjoining sectors may be incomparable, even if there are a number of species in common between the complexes. As a result some sectors may contain unique associations or assemblages of flora. This is not to imply that the components of the flora are rare or endangered but rather that the vegetation associations or complexes may be linked to a specific habitat which is not regionally widespread. This conclusion has implications for allocations of vegetation reserves and in assessment of regional significance of flora in environmental studies.

Adequacy of reserves in the Quindalup Dunes

Reserves for purposes of conservation are intended to preserve occurrences of rare and endangered flora and fauna, examples of vegetation assemblages, examples of landscape ecology, areas of scientific interest such as geological features, areas for research and education purposes, or to provide sanctuaries and security for a range of fauna and flora (Frith 1973, Lunney & Recher 1979, Messer & Mosley 1980, McMichael 1980, Ovington 1980, Dept of Conservation & Environment 1983a,b, Anon 1982, Leigh *et al* 1984). Indeed the various reserves in southwestern Australia have been established for a range of the above reasons. However, there is inadequate conservation of the variety of geomorphic, habitat and vegetation systems in the Quindalup Dunes. Where reserves are present in the Quindalup Dunes in the Perth metropolitan area there has been a tendency for undue emphasis in preserving the more seaward assemblages at the expense of the more landward assemblages.

It is also clear that the regional array of landforms and vegetation represents a wide spectrum of types and that a few reserves, as presently distributed, cannot adequately cover and secure sufficient representaion of this variability. It would be preferable to preserve examples of each of the vegetation formations, and associated geomorphology and geological features within the Quindalup Dunes.

The distribution of existing reserves in the Quindalup Dunes between Geographe Bay and Dongara is shown in Fig. 14. There are a number of other reserves in the Quindalup Dunes but these are for a range of purposes other than conservation of flora and fauna (such as recreation, camping, government requirements, explosive reserves).

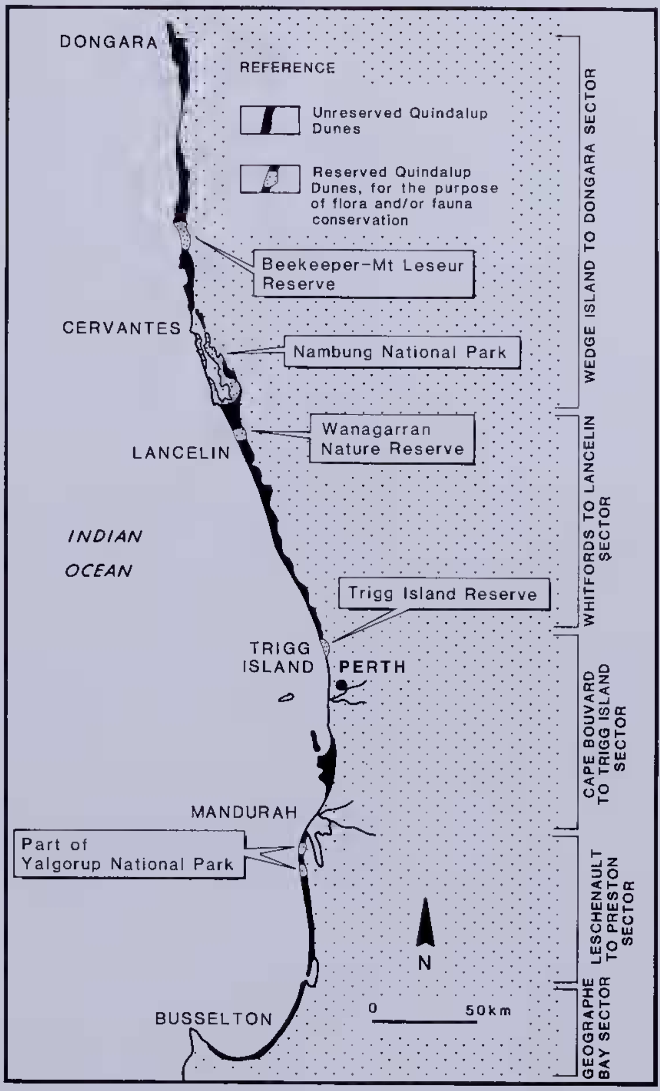


Figure 14 Location of reserves and national parks in the Quindalup Dunes.

Only five reserves cover areas of Quindalup Dunes, viz Beekeepers-Mt Lesueur Reserve, Nambung National Park, Wanagarran Nature Reserve, the Trigg Island Reserve and Yalgorup National Park. Three of these are located in Sector 5, but of these only one, Nambung National Park, adequately covers a significant area of the Quindalup Dunes, but even here the park does not extend to incorporate the major accretionary beachridge plain cusp in the area. The Wanagarran Nature Reserve covers a terrain of perched dunes and an accretionary cusp with blowouts and parabolic dunes. The Beekeepers-Mt Lesueur Reserve covers a portion of perched Quindalup Dunes in Sector 5. The Trigg Island Reserve covers a relatively small part of the perched dune system of Sector 4. Most of the Yalgorup National Park is located on the geomorphic unit, underlain by limestone and wetland deposits, termed by McArthur & Bartle (1980b) the Yoongarillup Plain, and the Quindalup Dunes comprise only some 5 km^2 of the National Park.

The essential features of the Quindalup Dunes that warrant conservation for each coastal sector throughout the southwestern coastal zone are listed in Table 5.

Table 5

Main natural features within each coastal sector and their conservation status

Coastal sector	Main natural features particular to a given sector	Conservation status[1]
Geographe Bay	barrier dune and shoreline dune ribbon with plains and parabolic dunes, respectively	none of the significant examples of this sector are conserved
Leschenault-Preston	barrier dune terrain composed predominantly of mobile and fixed parabolic dune systems	main significant portion not conserved[2]; Yalgorup National Park covers a small area of northern part which is not typical of this sector
Cape Bouvard-Trigg Island	cuspate beachridge plain composed of low relief shore-parallel sand ridges and intervening swales	no features of this sector conserved
Whitfords-Lancelin	perched dunes and accretionary cusps composed of (fretted, crescentic, attenuated) parabolic dunes and chaots	no examples of perched dunes and accretionary cusps are conserved
Wedge Island-Dongara	perched dunes composed of attenuated and fretted parabolic dunes, and accretionary cuspate forelands composed of low-relief shore-parallel sand ridges and intervening swales	perched dunes secured in Nambung National Park; examples of cuspate forelands not conserved

[1] Conservation status as at January 1987
[2] Although there are plans to reserve the Leschenault Peninsula as an example of this sector these plans have yet to be formalized.

This list of features illustrates the largely inadequate preservation of the variable Quindalup Dune systems. In many areas the major attributes that are specific or typical of a given sector are not reserved:

- the shoreline ribbon of the Geographe Bay Sector
- the barrier dune of the Leschenault-Preston Sector
- the cuspate beachridge plain centred on Becher Point and Rockingham, of the Cape Bouvard-Trigg Island Sector
- the perched dunes and accretionary cusps of the Whitford-Lancelin Sector
- the beachridge plain cusps of the Wedge Island-Dongara Sector

Hence there still is a need for conservation of areas of Quindalup Dunes and this should be based on their landform, scientific interest, representativeness, vegetation and relative lack of disturbance. It should be noted that there are still significant portions of the Quindalup Dunes that are listed as vacant crown land, land for government purposes or reserves for recreation etc., which could be revested or reallocated to become reserves for conservation of flora and fauna.

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